

The DRESHDYN project: planned experiments and present status

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The Dresden sodium facility for dynamo and thermohydraulic studies (DRESHDYN) is a platform for large-scale liquid sodium experiments devoted to fundamental geo- and astrophysical questions as well as to various applied problems related to the conversion and storage of energy. Its most ambitious part is a precession driven dynamo experiment, comprising 8 tons of liquid sodium supposed to rotate with up to 10 Hz and to precess with up to 1 Hz. Another large-scale set-up is a Taylor-Couette experiment with a gap width of 0.2 m and a height of 2 m, whose inner cylinder rotates with up to 20 Hz. Equipped with a coil system for the generation of an axial field of up to 120 mT and two different axial currents through the center and the liquid sodium, this experiment aims at studying various versions of the magnetorotational instability and their combinations with the Taylor instability. We discuss the physical background of these two experiments and delineate the present status of their technical realization. Other installations, such as a sodium loop and a test stand for In-Service-Inspection experiments will also be sketched.

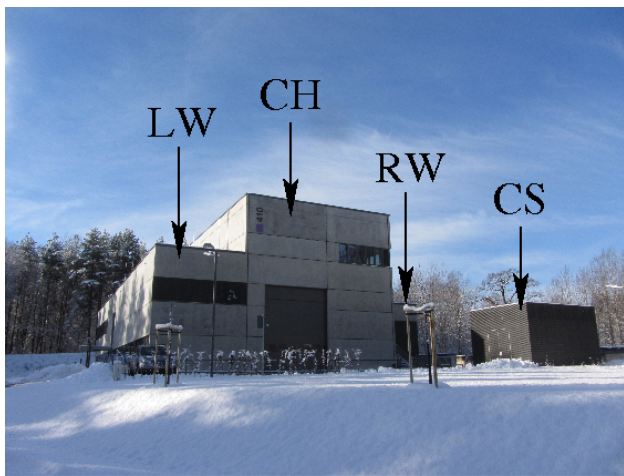
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1 Introduction

The large-scale infrastructure DRESHDYN (DRESden Sodium facility for DYNamo and thermo-hydraulic studies) at Helmholtz-Zentrum Dresden-Rossendorf is a platform for large- and medium-sized liquid-sodium experiments [1], partly devoted to fundamental problems of geo- and astrophysics, partly intended for investigations into energy-related topics, including various In-Service-Inspection (ISI) aspects [2] of Sodium-Fast-Reactors (SFRs), and stability problems of liquid metal batteries [3, 4]. In this paper, we will present the general structure of the DRESHDYN project, the main experimental installations and their scientific background.

2 DRESHDYN - An overview

The liquid sodium experiments will be carried out in a new laboratory building with approximately 500 m² experimental area. Figure 1a shows the completed DRESHDYN building from outside. Its left wing (LW) hosts a workshop, a chemistry lab, and a control room on the first floor. The central hall (CH) gives home to the liquid sodium experiments. The right wing (RW) contains most of the technical installations, in particular four sodium storage tanks for a total of 12 tons, an electricity supply for up to 2.4 MW, and a liquid argon fire extinguishing system with 15 tons of liquid argon. The cleaning station (CS) in the foreground will serve for the final cleansing of sodium-spoiled installation parts with water.



(a)



(b)

Fig. 1: The DRESHDYN building at HZDR. (a) External view, (b) interior of the central hall.

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Figure 1b shows the interior of the central experimental hall. The reddish wall in the background is part of a special containment for the large-scale precession experiment. The two horizontal trusses in the foreground provide the sodium experiments with cooling media, electricity, and control data. Figure 2 illustrates the overall structure and the planned installations, with the separate containment for the precession experiments (P), a large Taylor-Couette experiment (M) for investigations of the magnetorotational instability (MRI) and the Tayler instability, a sodium loop (L) and an ISI experiment (I).

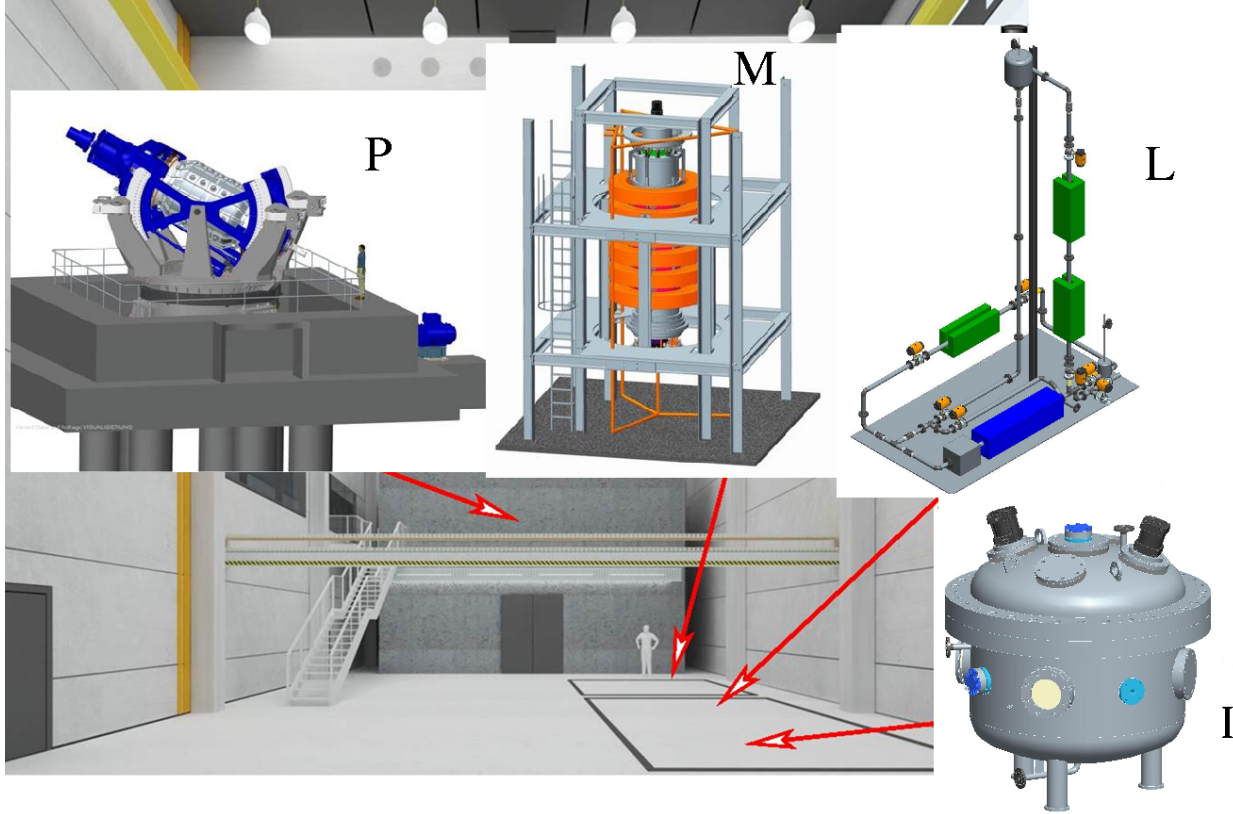


Fig. 2: Interior of the central hall, and the main planned experiments. Precession driven dynamo experiment (P) to be installed in the containment; Taylor-Couette experiment for the investigation of the magnetorotational and the Tayler instability (M); sodium loop (L); ISI experiment (I). A further stand for testing liquid metal batteries, which is not completely specified yet, will complement the list of sodium experiments.

The most ambitious project in the framework of DRESHDYN is certainly the large scale precession experiment (P) which is intended to continue the recent efforts in Riga [5], Karlsruhe [6], Cadarache [7] and elsewhere to investigate homogeneous dynamo action in the liquid metal lab.

One of the key questions of geo- and astrophysical magnetohydrodynamics concerns the energy source of different cosmic dynamos. While thermal and/or compositional buoyancy is considered the favourite candidate, precession has also been discussed as a complementary energy source of the geodynamo [8, 9], in particular at an early stage of Earth's evolution, prior to the formation of the solid core. Some influence of orbital parameter variations can also be inferred from paleomagnetic measurements that show an impact of the 100 kyr Milankovic cycle of the Earth's orbit eccentricity on the reversal statistics of the geomagnetic field [10, 11]. Recently, precessional driving has also been discussed in connection with the generation of the lunar magnetic field [12], and with dynamos in asteroids [13]. In which parameters precession can drive a dynamo is still a matter of debate. While some simulations in cylinders and cubes, carried out at magnetic Prandtl numbers $Pm \approx 1$, had found dynamo action for magnetic Reynolds numbers $Rm \approx 600$ [14–16], more recent simulation at lower Pm have pointed to less optimistic values [17, 18].

The DRESHDYN precession experiment consists of a cylindrical vessel of 2 m diameter, 2 m height, and 3 cm wall thickness, supposed to rotate with up to 10 Hz around its axis, and with up to 1 Hz around a perpendicular axis. The mechanical and safety demands for such a large-scale sodium experiment are tremendous, in particular due to the huge gyroscopic torque (up to 8 MNm) which requires a massive ferro-concrete basement which rests on 7 columns reaching 22 m into the bedrock.

A second experiment with geo- and astrophysical background is a liquid sodium Taylor-Couette experiment (M) that is supposed to continue and combine the recent experiments (using GaInSn) on the helical [19] and the azimuthal [20] versions of the magnetorotational instability (MRI) and on the Tayler instability (TI) [21]. Its main goal, however, is to enhance the available parameter region in such a way that standard MRI [22, 23] should become reachable [24]. Its central part is a sodium filled Taylor-Couette cell with a gap width of 0.2 m and a height of 2 m, whose inner cylinder rotates with up to 20 Hz which

corresponds to $Rm \approx 40$. Equipped with a coil system for the generation of an axial field of up to 120 mT (giving a Lundquist number $S \approx 40$) and two different axial currents through the center and the liquid sodium, this experiment aims at studying various versions of the magnetorotational instability and their combinations [25] with the Tayler instability which might play an important role for the planetary synchronization of the solar dynamo [26].

The TI will also play a central role in a third experiment in which different flow instabilities in liquid metal batteries (LMB) will be studied. LMBs consist of three self-assembling liquid layers [27], an alkali or earth-alkali metal (Na, Mg), an electrolyte, and a metal or half-metal (Bi, Sb). In order to be competitive, LMBs have to be quite large, so that charging and discharging currents in the order of some kA are to be expected. Under those conditions, TI [3, 4], electrovortex flows [28], and interface instabilities [29], must be carefully avoided or at least controlled.

Further to this, DRESHDYN will also comprise a standard sodium loop (L in figure 2), with a horizontal and a vertical test section of diameter 100 mm. A 30 kW electromagnetic pump will provide a maximum flow rate of 56 m³/h. Both test sections will be equipped with various measurement flanges, and will optionally allow the application of magnetic fields in order to investigate particular MHD flow problems. The vertical test section will be used for investigations of two-phase flows of sodium and argon, in particular using Mutual Induction Tomography [30].

Another experimental test stand (I in figure 2) will be utilized for ISI experiments and tests of measurement techniques. Important flow measurement methods to be tested are the Ultrasonic Doppler Velocimetry (UDV) [31,32] and various inductive methods such as the phase-shift sensor [33] and the transient eddy-current flow meter (TECFM) [34]. Besides of being calibration-free, TECFM is particularly interesting since the absence of any magnetic materials makes it suitable for high-temperature applications as they are relevant for SFRs. In addition to these local methods, we will also validate a global inductive method that aims at reconstructing entire velocity fields [35]. This Contactless Inductive Flow Tomography (CIFT) relies on the fact that externally applied magnetic fields are disturbed by the flow of a conducting medium. These small flow-induced modifications of the magnetic field are measured outside the liquid metal volume using an array of magnetic field sensors. By using this method, it is possible to reconstruct whole two-dimensional or three-dimensional velocity fields.

3 Conclusion

In this paper, we have presented the DRESHDYN project as a platform for medium and large-scale liquid sodium experiments, partly with geo- and astrophysical motivation, partly related to energy technology problems. The sodium infrastructure is expected to become available by the end of 2017, so that first sodium experiments could start in 2018. Apart from the specific experiments discussed in this paper, DRESHDYN is open for proposals of further liquid sodium investigation. A large-scale Rayleigh-Bénard experiment, potentially rotating and/or under the influence of a magnetic field, might be a case in point.

Acknowledgements Financial support of this research by the German Helmholtz Association in the frame of the Helmholtz-Alliance LIMTECH is gratefully acknowledged.

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